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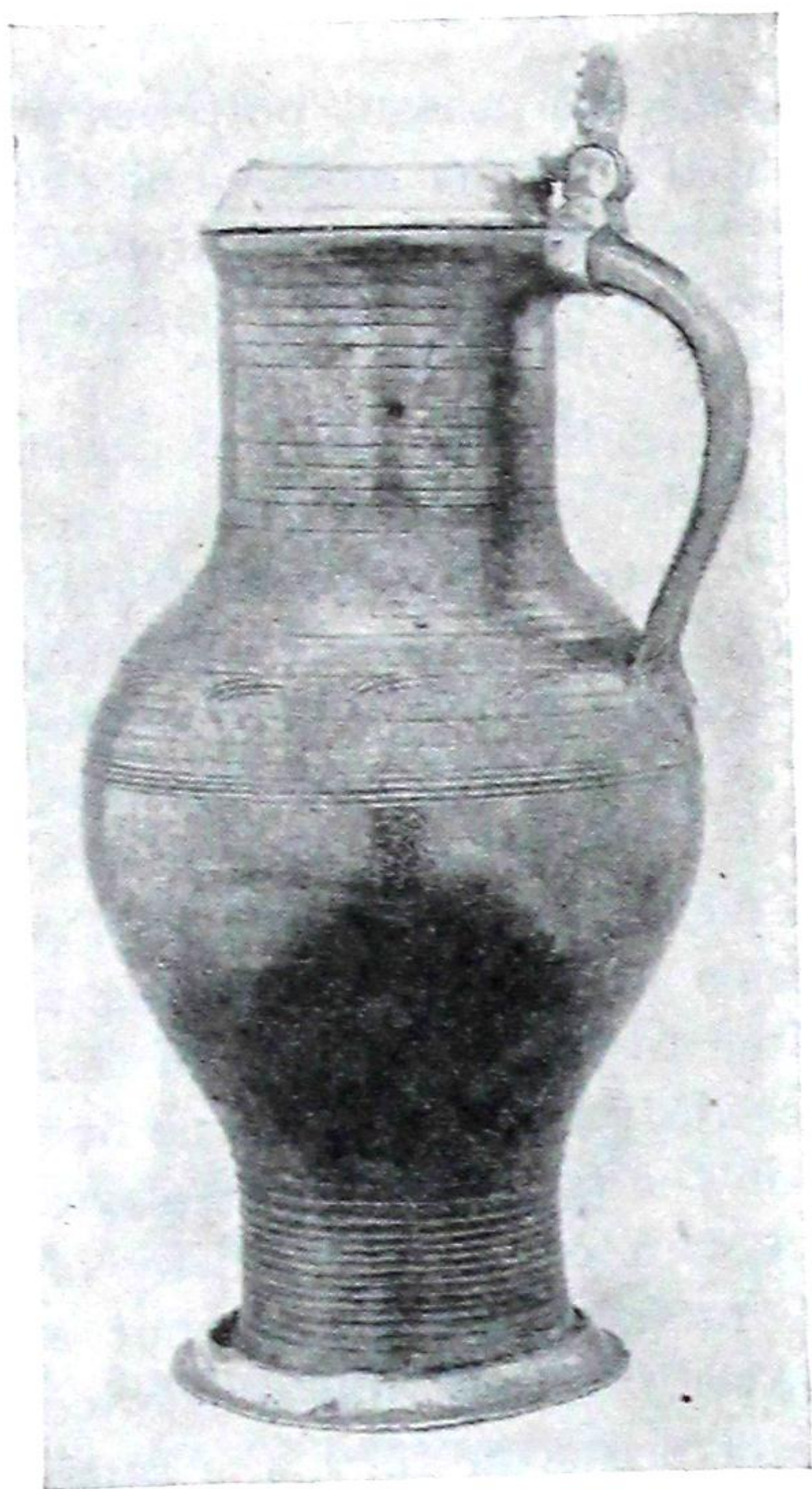
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Germany

It was in Germany that stoneware was first produced in Europe. Early in the 15th century a dark reddish stoneware was being made in the Rhenish country near Cologne. Salt glaze, which was a complete departure from other types of glazes, made its first appearance. Like



Metropolitan Museum of Art

FIG. 1-8. Salt-glazed German stoneware beer stein, probably 15th Century.

many other ceramic processes it was probably discovered through accident, the chance introduction of salt into the fire boxes.

By the 16th century there were many flourishing ceramic centers producing great varieties of stoneware. The need for ornament was satisfied by decorations in relief; this was fostered by the character of the glaze, which was thin and would not obscure the modeled details. For the most part the wares were wheel-thrown, comprised chiefly of jugs, ewers, steins, bowls and bottles upon which decorations were sometimes incised. The usual treatment was to cut the ground to leave the details in relief or to press ornamental devices in molds and lute these to the wares. Underglaze decorations were sometimes painted in cobalt blue, but this color was ordinarily employed to accentuate the modeling.

Some tin-enameled wares of the Italian type were made during the 16th and 17th centuries. In Germany, however, this ware was not received

at all favorably and was always overshadowed by the production of stoneware.

The Netherlands

Guido di Savino, from Castel Durante, established a pottery in Antwerp in the 16th century. This flourished and soon other factories sprang up to produce tin-enameled wares in the Italian manner. During the middle of the century, to avoid religious persecution, the potters fled north and established their potteries in various other cities, among which Delft soon took precedence. The wares were Italian in style but with an admixture of Dutch elements. The decoration took on a new character

tite ($\text{MgO} \cdot \text{SiO}_2$). We shall hear more of both later in the discussion of special high-frequency porcelains.

The first additions of MgO to SiO_2 lower the melting temperature only slightly; the total lowering of the melting temperature of the mixture amounts to no more than 18°C . until the MgO content exceeds 31%, then an additional 5% of MgO drops the melting point another 150°C . The reason is that, up to the eutectic point, MgO and SiO_2 resist melting each other and therefore make a good working team for use in refractories. An opposite effect is gained through the use of the alkali oxides, which form completely miscible liquids with silica and give a very rapid decrease in the melting temperatures of the mixtures. The latter effect explains why the alkali oxides act as fluxes in ceramic compositions. In this regard, it is noteworthy that the oxides of the metals with lightest atomic weights—those of potassium, sodium, and lithium—are among the most powerful fluxes for use in ceramics.

Looking again at Fig. 2-5, we see that clinoenstatite melts incongruently at $1,557^\circ\text{C}$., forming forsterite and a liquid. Forsterite, which melts at the high temperature of $1,890^\circ\text{C}$., has become an important refractory material in recent years. Note how the liquidus curve drops abruptly in the diagram, showing how even a small amount of excess silica would seriously lower the melting point of forsterite.

Natural steatite talc, when heated to about $1,250^\circ\text{C}$., produces almost the eutectic composition, but is slightly richer in silica. Therefore all of the available MgO is combined with silica to form clinoenstatite, and the excess silica, amounting to about 15% of the total, forms cristobalite. Cristobalite, though stable at higher temperatures, is unstable at $1,250^\circ\text{C}$. and slowly inverts to tridymite.

The Soda-Silica System

Another two-component system of usefulness in the ceramic field is the soda-silica system, which, along with the ternary soda-lime-silica system, is the basis of the simpler types of glasses and glazes. The alkali oxides form completely miscible liquids with silica, giving a rapid decrease of the melting temperature of the mixture, as shown in Fig. 2-6, where Na_2O is seen to exert a powerful effect on the melting point of silica.

Pure silica melts at $1,713^\circ\text{C}$., but a mix of 74% silica and 26% soda has a melting point of only 793°C ., a decrease of more than 900°C . Such fusible alkali silicates constitute the simplest glasses, but are readily soluble in water and therefore of no practical use for applications requiring a resistant type of glass. They are nevertheless of value in making water glass, which has its own use as an adhesive and in other special applications.

The chief value of bentonite lies in its extreme plasticity; the plasticity added to ceramic bodies through its use greatly exceeds that introduced by any other material. For many commercial bodies, a 2% addition of bentonite improves the plasticity more than the addition of 10% of ball clay. A typical chemical analysis of a type I bentonite from the Black Hills area of South Dakota-Wyoming is as follows:

<i>Component</i>	<i>Per cent by weight</i>
Silica.....	64.32
Alumina.....	20.74
Iron oxide.....	3.49
Lime.....	0.46
Magnesia.....	2.26
Alkalies.....	2.90
Titanium dioxide.....	0.11
Sulfur.....	0.35
Ignition loss.....	5.15

Bentonite's high iron oxide content militates against the use of amounts much larger than 2 to 3% in articles where fired color is important. The material also has very high shrinkages in drying and firing.

NON-PLASTIC MATERIALS

Flint

Flint is the potter's term for the finely pulverized powder made of white quartzite sand which is mined chiefly in Illinois, West Virginia and Pennsylvania. Chemically, the material is pure silica, SiO_2 , the most important batch ingredient in the entire field of ceramic manufacture. Few indeed are the commercial ceramic products which do not contain silica as an important constituent. For this reason the ceramic industry is often called the silicate industry.

As discussed in Chapter 2, silica, whether added in the form of flint or by some other method, goes through a series of complicated crystal changes at different temperatures. These changes are accompanied by volume changes, some of which are rather large. For example, that accompanying the conversion of beta-quartz to tridymite is an expansion of about 15%. These abrupt volume changes cause strains in ceramic bodies and limit their usefulness in applications where appreciable temperature differences are encountered.

Flint is a non-plastic in unfired bodies, as its individual particles are hard and non-absorbent. By its addition the workability and drying shrinkage of the body are lowered, and drying behavior and strength are improved. In the fired body, flint adds strength, toughness and hardness, thereby enhancing all the mechanical strength properties of the body.

(albite). Mineralogically it resembles granite but contains no free quartz. Considerable quantities are imported annually from Canada for use as a flux in ceramic bodies. After removal of magnetic iron, the commercial material contains 60.24% silica, 24.05% alumina, 10.03% soda and 5.01% potash. The only significant impurity present is lime, in the amount of 0.15%.

Nepheline syenite is used chiefly as a replacement for part or all of the feldspar as the flux. It begins to sinter at Cone 02 and has a P.C.E. of about Cone 7. An eutectic which forms between the nepheline and the soda feldspar contributes to the long sintering range of nepheline syenite.

In unfired bodies, nepheline syenite behaves similarly to feldspar. However, due to its fluxing action at lower temperatures, it lowers the firing temperature of the ware, making possible faster firing schedules. Truly vitreous bodies, made from clays and nepheline syenite, have been matured at Cone 3 without use of an auxiliary flux. In general, it may be said that the use of nepheline syenite permits a lower maturing temperature and longer firing range, increases strength and decreases absorption, as compared with similar bodies fluxed with normal feldspars which have potash as the predominant alkali.

TABLE 3-3. Analyses of Ceramic Talc

Sample from	Per cent by weight						
	SiO ₂	MgO	Al ₂ O ₃	Fe ₂ O ₃	CaO	Na ₂ O K ₂ O	Ignition loss
STEATITE GRADES							
Heyman Co. "MK 1", India.....	61.24	32.42	1.42	0.02	—	—	4.90
W. H. Loomis Talc Corp. Steatite Grade.....	65.75	24.49	1.30	1.30	3.31	—	4.81
Sierra Talc Co. Hi-Grade No. 1.....	60.56	30.19	1.46	0.90	0.80	0.22	5.68
Sierramic No. 1.....	59.61	30.01	1.65	0.92	0.84	0.26	5.94
Whittaker, Clark and Daniels Manchuria, No. 100.....	60.18	33.30	0.36	0.32	0.08	0.28	5.48
NON-STEATITE GRADES							
W. H. Loomis Talc Corp. Ceramic Grade.....	56.97	30.75	1.15	1.15	5.56	—	5.67
Sierra Talc Co. "CB" Ceramic.....	57.89	27.79	1.71	0.42	9.11	0.36	2.39
Fibrene "B".....	49.51	23.92	2.01	0.44	10.59	1.22	11.84

property, in addition to being associated with extreme chemical resistance, makes the material suitable for chemical ware and special refractories.

In normal whiteware bodies, zircon adds greatly to flexural strength; high zircon bodies (70%) have shown strengths in excess of 12,000 p.s.i. The low and regular thermal expansion makes zircon of value in certain types of high-talc bodies to increase the firing range. Its high dielectric strength at elevated temperatures is also of value in such bodies, as well as in high-titania insulator bodies where it is sometimes used.

The Sillimanite Group

There are in the so-called sillimanite group three separate minerals—andalusite, kyanite, and sillimanite—all of which have the same chemical formula, $\text{Al}_2\text{O}_3 \cdot \text{SiO}_2$. There are, however, important differences between them; andalusite and sillimanite crystallize in the orthorhombic form, while kyanite has a triclinic structure. Each of the three decomposes upon heating, giving mullite, $3\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$, and probably a silicate glass. The temperatures at which these decompositions begin to take place, as well as some other specific properties of the three materials, are:

Properties	Andalusite	Kyanite	Sillimanite
Specific gravity.....	3.16	3.60	3.23
Mohs' hardness.....	7.5	4-7	6-7
Temperature of decomposition.....	2,460°F.	2,390°F.	2,786°F.

Of the three, kyanite is by far the most plentiful in the United States; commercial deposits are located in North Carolina, Georgia, and California. The only working mine of andalusite is located in Mono County, Calif. Small deposits of sillimanite are also located in California but they are not of commercial importance. The chief world source for all three minerals is India.

In ceramic bodies the three materials behave similarly. Under heat treatment they develop mullite crystals, which greatly improve the strength, thermal resistance, and spalling resistance of the body. Andalusite is used chiefly in spark-plug porcelain, as the only mine in the country is owned by a large spark-plug manufacturer.

True Indian sillimanite has been used very little in the United States, though the name sillimanite is sometimes applied to refractories containing large quantities of mullite—added to the body in the form of kyanite. Sillimanite, however, is an excellent material for use in high-temperature porcelain insulators and special refractory purposes, as it is strong, tough, has only moderate shrinkage, a low coefficient of expansion, and is chemically resistant to most slags.

Most of these materials are complex chemical compounds, usually silicates, but their constitution is such that the composition can be expressed in terms of simple oxides. For example, pyrophyllite has the chemical formula $\text{H}_2\text{Al}_2(\text{SiO}_3)_4$, being an aluminosilicate, but for convenience the ceramist considers the material as $\text{Al}_2\text{O}_3 \cdot 4\text{SiO}_2 \cdot \text{H}_2\text{O}$, which gives the same number of each kind of atoms in the molecule of pyrophyllite. This practice of referring to ceramic materials and ceramic products in terms of their component oxides no doubt stems from the fact that chemical analysis shows that they contain enough oxygen to supply all the other elements as if they were actually present as simple oxides. The oxide method of expression makes it much easier to understand the effects which any given material may have on the batch as a whole, and greatly simplifies the calculations needed when one material is substituted for another.

Because of this method of handling batch calculations, it is imperative that the ceramic engineer be well grounded in the chemistry of oxides. The oxides may be divided into three groups chemically: the oxides of the metallic elements, which are called the basic oxides; oxides of the non-metallic elements, called the acid oxides; and oxides of the (amphoteric) elements which may function either as metals or non-metals, called neutral oxides. In Table 4-1 are given some of the more common oxides in each group, and their molecular weights, to the nearest whole number.

TABLE 4-1. Grouping of Common Oxides

Basic oxides		Neutral oxides	Acid oxides
RO	R ₂ O	R ₂ O ₃	RO ₂
CaO— 56	Na ₂ O—62	B ₂ O ₃ — 70	SiO ₂ — 60
MgO— 40			
BaO—153	K ₂ O—94	Al ₂ O ₃ —102	TiO ₂ — 80
FeO— 72			
MnO— 71	Li ₂ O—30	Fe ₂ O ₃ —160	ZrO ₂ —123
PbO—223			
CdO—128		Cr ₂ O ₃ —152	
ZnO— 81			
BeO— 25		Sb ₂ O ₃ —292	

It will be noted that these oxides are in a logical arrangement, in that all of the basic oxides are of the RO or R₂O type (R being a symbol to indicate any element other than oxygen), the neutrals are all of the R₂O₃ type, and the acid oxides have the RO₂ construction. Actually, B₂O₃ is acidic in character and should be placed in the acid group, but in ceramic bodies it acts as a neutral and can be used as a substitute only for other

neutral oxides. Therefore we place it in the neutral group to be used as the basis for batch calculations.

In Table 4-2 are given the common elements with which the ceramic engineer is primarily concerned, their symbols and atomic weights.

TABLE 4-2. Common Chemical Elements

Element	Symbol	At. wt.	Element	Symbol	At. wt.
Aluminum.....	Al	26.97	Magnesium.....	Mg	24.32
Antimony.....	Sb	121.77	Manganese.....	Mn	54.93
Arsenic.....	As	74.93	Nickel.....	Ni	58.69
Barium.....	Ba	137.36	Nitrogen.....	N	14.01
Beryllium.....	Be	9.02	Oxygen.....	O	16.00
Bismuth.....	Bi	209.00	Phosphorus.....	P	31.04
Boron.....	Bo	10.82	Potassium.....	K	39.10
Cadmium.....	Cd	112.41	Silicon.....	Si	28.06
Calcium.....	Ca	40.07	Sodium.....	Na	23.00
Carbon.....	C	12.00	Strontium.....	Sr	87.63
Chlorine.....	Cl	35.46	Sulfur.....	S	32.06
Chromium.....	Cr	52.01	Tin.....	Sn	118.70
Cobalt.....	Co	58.94	Titanium.....	Ti	47.90
Copper.....	Cu	63.57	Tungsten.....	W	184.00
Fluorine.....	F	19.00	Uranium.....	U	238.14
Hydrogen.....	H	1.01	Vanadium.....	V	50.96
Iron.....	Fe	55.84	Zinc.....	Zn	65.38
Lead.....	Pb	207.22	Zirconium.....	Zr	91.22
Lithium.....	Li	6.94			

The Empirical Formula

As already stated, the ceramist has developed the practice of expressing the composition of inorganic materials in terms of oxides. In this way he can estimate the properties of a given compound, because he knows the properties of the individual oxides it contains. The same practice is used for calculating the formulae of ceramic bodies and glazes. The body or glaze is considered as a chemical compound—a mixture of oxides—and its percentage composition expressed by the empirical formula which is of the same form as a molecular formula, but does not represent the true structure of a molecule.

The method of doing this may be learned by studying the following example, which is based on the analysis of a feldspar:

Oxide	Per cent		Mol. wt.		Equivalents
CaO	0.12	÷	56	=	0.002
K ₂ O	13.46	÷	94	=	0.14
Na ₂ O	2.08	÷	62	=	0.03
SiO ₂	65.42	÷	60	=	1.09
Al ₂ O ₃	18.24	÷	102	=	0.18
Total	98.32				

The oxides shown in the analysis are only those present in pure feldspar; iron, titanium, organic matter and volatiles are also present in limited amounts. For this reason the total weight of oxides shown is less than 100%. Thus the formula which will be calculated from this analysis is empirical and will not exactly duplicate the molecular ratios of a pure compound.

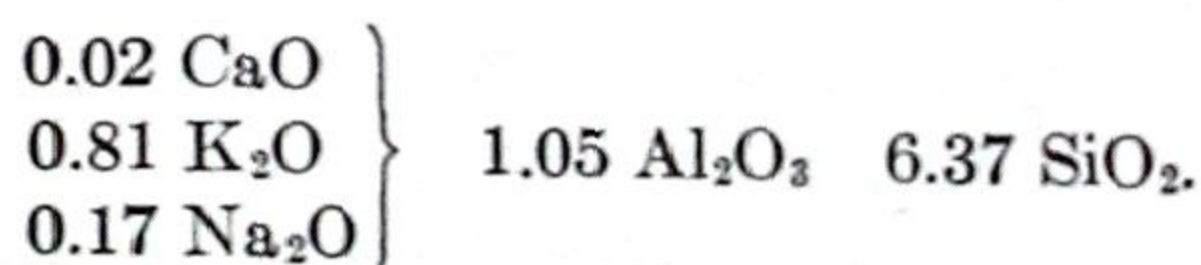
Having divided the amount of each oxide by its own molecular weight, we have derived the expression shown as "equivalents," indicating the proportions of each oxide present. In ceramic calculations the total of the RO group (including R_2O type oxides) is brought to unity when glazes are calculated; the R_2O_3 group is brought to unity for body calculations. In this case the total of RO equivalents is:

<i>Component</i>	<i>RO equiv.</i>
CaO	0.002
K ₂ O	0.14
Na ₂ O	0.03
Total	0.172

Each equivalent is then divided by this number:

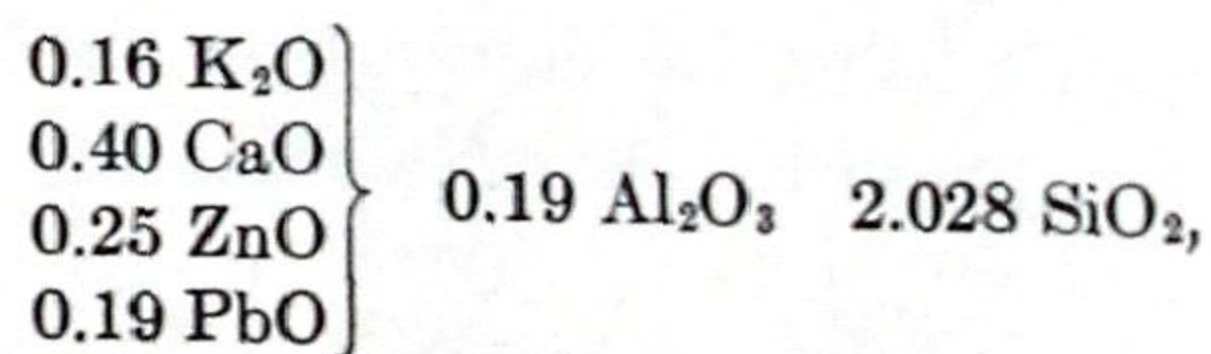
<i>Component</i>	<i>Equivalent</i>	<i>Total RO equivalent</i>			
CaO	0.002	÷ 0.172	=	0.02	} = 1.00
K ₂ O	0.14	÷ 0.172	=	0.81	
Na ₂ O	0.03	÷ 0.172	=	0.17	
SiO ₂	1.09	÷ 0.172	=	6.37	
Al ₂ O ₃	0.18	÷ 0.172	=	1.05	

Arranged by oxide groups in the order RO : R_2O_3 : RO_2 , the empirical formula then becomes:



A theoretically pure potash feldspar, as noted in Chapter 3, would have the formula $1 \text{ K}_2\text{O} \cdot 1 \text{ Al}_2\text{O}_3 \cdot 6 \text{ SiO}_2$, which is expressed: $\text{K}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 6\text{SiO}_2$.

When the empirical formula of a ceramic body, glaze or raw material is given, the chemical composition may be calculated by reversing the above procedure. For example, given a glaze with the empirical composition,



to make it clear that two molecules of NaNO_3 are required to provide one of Na_2O . Thus, the equivalent weight of NaNO_3 with respect to Na_2O is twice its molecular weight, or 170. Similarly, when changes of valence occur in the reaction that produces the oxide, it is again necessary to write the proper equations in order to determine the relationship between equivalent weight and molecular weight. A listing of the most common ceramic materials and their equivalent weights is given in Table 4-3.

Some of these compounds, such as the carbonates, give off gases which, by definition, should be indicated in the RO_2 list of equivalents. However, the gases are not present in the fired ceramic body; therefore the indicated material would never be used for the addition of such compounds. For this reason their equivalent values are omitted from Table 4-3, which is intended as a working table of practical interest to the engineer.

Formula Batch Weight

The formula batch weight of a ceramic composition is the equivalent weight of the raw batch recipe. It is, therefore, determined by the raw batch, before firing, and includes any contained gases or volatile ingredients which may be lost during firing. The formula batch weight, then, is the equivalent weight of the batch with respect to the final fired material.

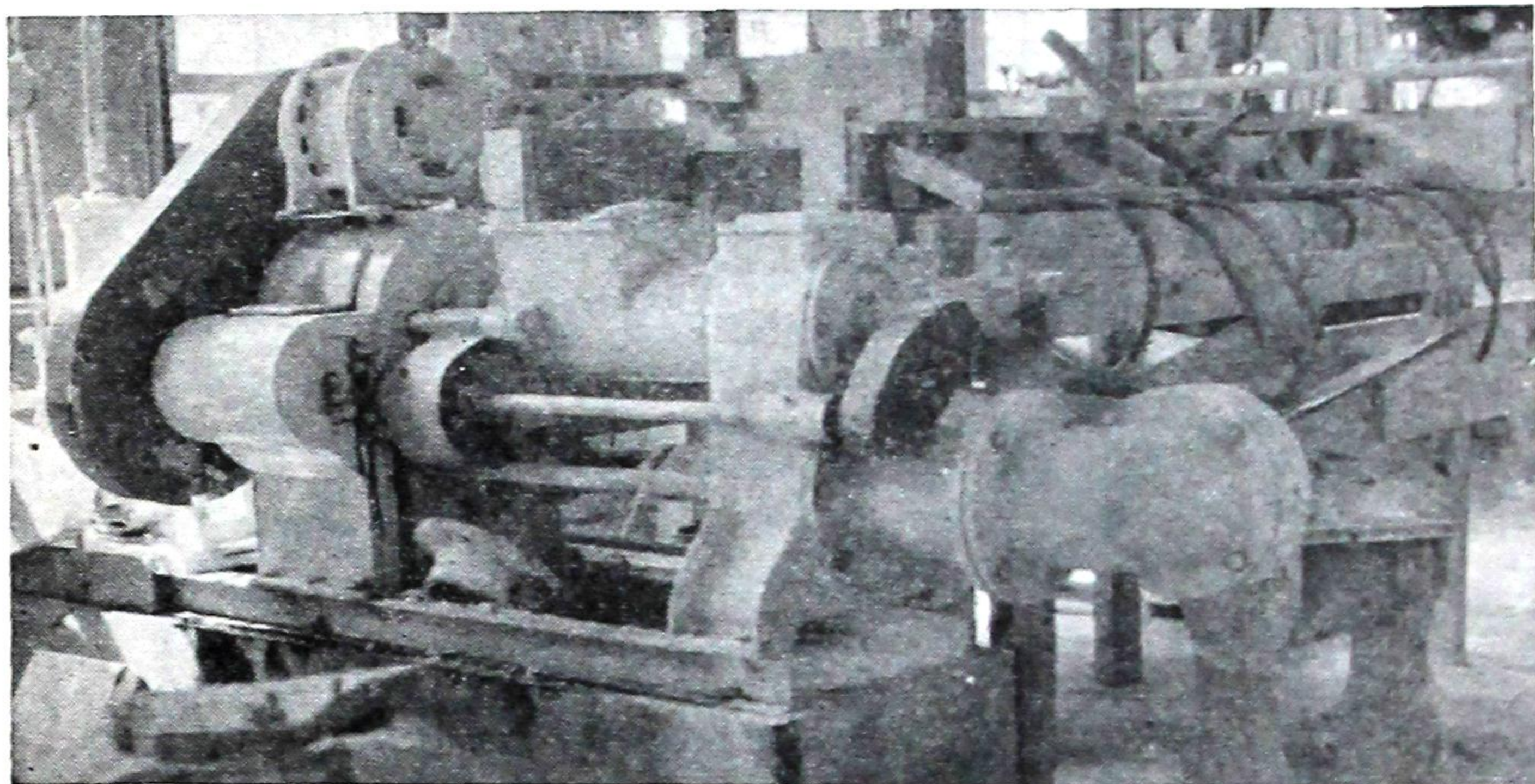
The methods of calculation referred to herein are much more commonly used in compounding glasses and glazes than for ceramic bodies, and their use is demonstrated more fully in the discussion of glazes in Chapter 8.

Rational Analysis

Another tool of the ceramist is the type of calculation known as rational analysis. The ordinary chemical analysis, or ultimate analysis, shows the constituents of a body only in terms of chemical compounds, usually oxides. In many cases the ceramist prefers to have some data of a mineralogical nature, as the properties of a body can vary greatly, depending upon the form in which the different ingredients are added. For example, the different silica minerals—quartz, cristobalite and tridymite—have considerably different physical properties, even though each would analyze pure SiO_2 and be shown as such in a chemical analysis.

The rational analysis is used to divide the mineral content of a clay into flint (quartz), feldspar and clay substance. The clay substance is made up of kaolinite or other similar hydrated aluminum silicates (including micas) which may be dissolved from the other constituents through the use of boiling sulfuric acid and sodium carbonate. Of the residue,

The de-airing machine insures that any voids in the clay will be completely empty, with no air present to prevent the clay from sealing together in a solid column. Its use in the past 20 years has greatly improved the quality of ceramic whitewares formed by plastic processes. Without the de-airing machine it is highly doubtful whether ceramic



Ceramic Industry

FIG. 4-7. Stainless steel, aluminum, and bronze pug mill at the T.V.A. ceramic research laboratory.

bodies could be satisfactorily produced on the high-speed automatic jigger machines which have become of such great importance in the past ten years.

DRY PRESS BODIES

Filter press cakes have an average water content of about 20%; body mixtures for the dust press method of ware forming normally contain not over half that amount. The balance can quite readily be removed by merely storing the press cakes for a few days, letting simple evaporation do the job. This practice is followed in many plants. The press cakes then are granulated in some type of pulverizer, screened, and moisture added if necessary. A much more common method of preparing bodies for dry pressing is known as the "dry mixing" method which differs completely from the blunging-pressing-de-airing sequence just described.

Dry Mixing

The past few years have seen the introduction and growth of a new, simpler method of preparing ceramic batches, commonly called dry mixing. This method is built around a blending mixer which actually is a

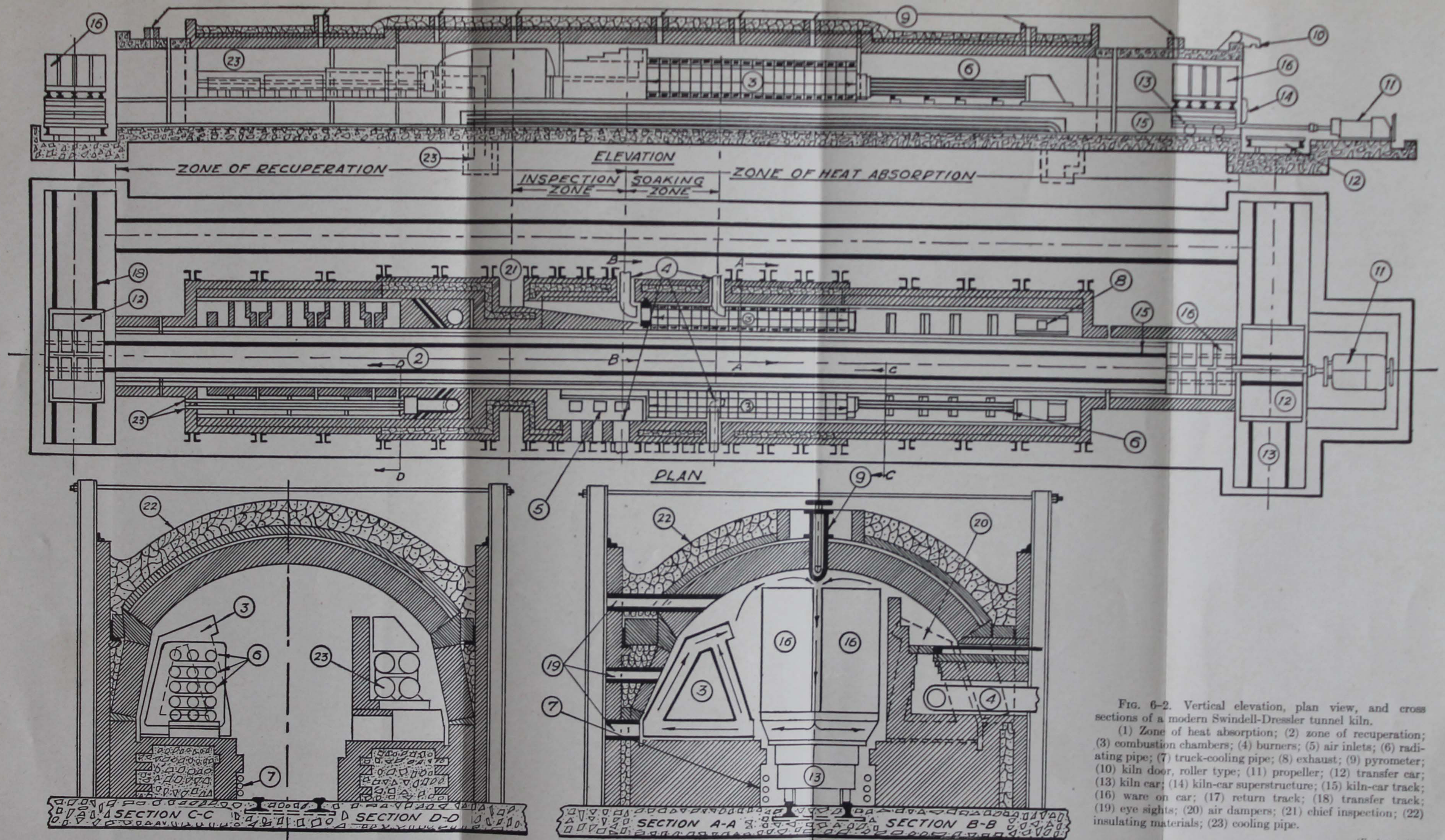


FIG. 6-2. Vertical elevation, plan view, and cross sections of a modern Swindell-Dressler tunnel kiln.

(1) Zone of heat absorption; (2) zone of recuperation; (3) combustion chambers; (4) burners; (5) air inlets; (6) radiating pipe; (7) truck-cooling pipe; (8) exhaust; (9) pyrometer; (10) kiln door, roller type; (11) propeller; (12) transfer car; (13) kiln car; (14) kiln-car superstructure; (15) kiln-car track; (16) ware on car; (17) return track; (18) transfer track; (19) eye sights; (20) air dampers; (21) chief inspection; (22) insulating materials; (23) cooling pipe.

various sources in the literature of the industry. Of particular interest are the compositions given for Cones 14 and 20. These correspond exactly to the ingredients of Seger pyrometric Cones 8 and 13, respectively. It is common practice for the experimenting glaze chemist to use Seger cone compositions as a working base. The temperatures are different, of course, because a mixture that begins to soften and deform at, say, Cone 8, would not become fluid enough to be useful as a glaze until it reached a temperature six or seven cones higher.

TABLE 8-3. Compositions of High Fusing Glazes—in Equivalents

Component	Fusion temperatures—cones				
	12	14	16	18	20
K ₂ O	0.20	0.30	0.15	0.25	0.30
CaO	0.40	0.70	0.65	0.60	0.70
ZnO	0.30	—	—	—	—
BaO	0.05	—	—	0.10	—
MgO	0.05	—	0.20	0.05	—
Total RO	1.00	1.00	1.00	1.00	1.00
Al ₂ O ₃	0.5	0.8	1.0	1.35	1.60
SiO ₂	4.0	8.0	10.0	14.00	16.00
B ₂ O ₃	0.1	—	—	—	—

Note the regular increase in the silica content of the glazes in this table. It is readily apparent, also, that all these glazes are glossy, as their alumina-silica ratios are all 1 : 8 or higher; normal mat glazes have much lower ratios.

We note that both PbO and Na₂O have disappeared completely from the RO group; K₂O and CaO are the principal fluxes. The K₂O is usually introduced in potash feldspar, as the other potash compounds are soluble and therefore would require fritting of the glaze.

Crystalline Glazes

Very beautiful decorative effects are often obtained on artware through the use of crystalline glazes, which are saturated with one or more crystal-forming ingredients at the fusing temperature, with the result that these ingredients crystallize as the glaze is slowly cooled. ³Lane contends there are about 16 compounds that produce crystals under certain conditions. Of these, zinc oxide is by far the most widely used, and often amounts to 60% of the RO group. The crystals it produces are a complex zinc silicate. Manganese oxide is also often used.

them to withstand severe freezing. Made by either the dust-press or plastic process, these durable tile are suited for use on exterior walls, store fronts and on floor areas not exposed to heavy wear. Tile of this type are often used in vehicular tunnels, subways, refrigerator rooms, swimming pools and similar structures. They are made in a wide variety of shapes and sizes, glazed in many colors, conforming to the practice already mentioned in the discussion of glazed interior tile.

Pavers. Pavers are unglazed tile, much like ceramic mosaics in composition and properties. They differ from mosaics only in size, having a face area greater than 6 sq. in.; the most common sizes fall between 3×3 and 6×6 in. When made of a whiteware body by the dust-press process, pavers are either impervious or vitreous. When made from natural clays by the plastic process, they may be vitreous or semi-vitreous; if natural clays are dust-pressed the impervious grade is sometimes obtained. All pavers are resistant to weather and well suited to withstand heavy floor service. The impervious grade makes an excellent flooring material for dairies, slaughterhouses and similar applications where sanitation considerations require ceramic flooring.

Natural Clay Tiles. The foregoing discussion covers the principal types of tile made entirely or in part from whiteware body mixtures. There are some other types, however, made entirely from natural clays, which should be mentioned here because they compete directly with the whiteware tile. Perhaps the most important of these is known as quarry tile, unglazed floor tile made by the plastic process. Quarries have a very dense body, with colors predominantly in the red to brown range, depending upon the iron oxide content of the clay used. Sizes range from 1-in. squares to 12-in. squares; most important are the $6 \times 6 \times \frac{3}{4}$ in., $6 \times 9 \times \frac{3}{4}$ in. and the $9 \times 9 \times \frac{7}{8}$ in. Quarries are extremely durable and resistant to moisture, stains, abrasion and freezing. These properties have encouraged their wide use for floors in apartments, hotel lobbies, gardens, terraces, school halls and stairways, and for many similar uses in other types of public buildings.

Faience Tile. Faience tile, which derive their name from the ceramic center of Faenza, Italy, are formed by plastic processes and coated with colored glazes. The body may range from non-vitreous to vitreous, depending upon the firing behavior of the clays. The vitreous grade may be used for exterior work, while the non-vitreous is limited to applications where freezing will not be encountered. Faience tile are made in many sizes, ranging from 1-in. to 12-in. squares. Pieces with less than 6 sq. in. face area are called faience mosaics. They are given many types of glaze finishes and often have designs in relief pressed into the face. When mat glazes are used, faience tile are suitable for flooring where wear is not too

Closet-Bowls

The most important type of unit, from dollar-volume statistics, is the common toilet, known in the industry by the supposedly more refined names "closet-bowl" and "water-closet." These may be subclassified in several different ways; the most logical breakdown separates the units which include a water tank (known as water-closet combinations) from those which are connected directly to the water supply through direct flushing valves and therefore require no tanks.

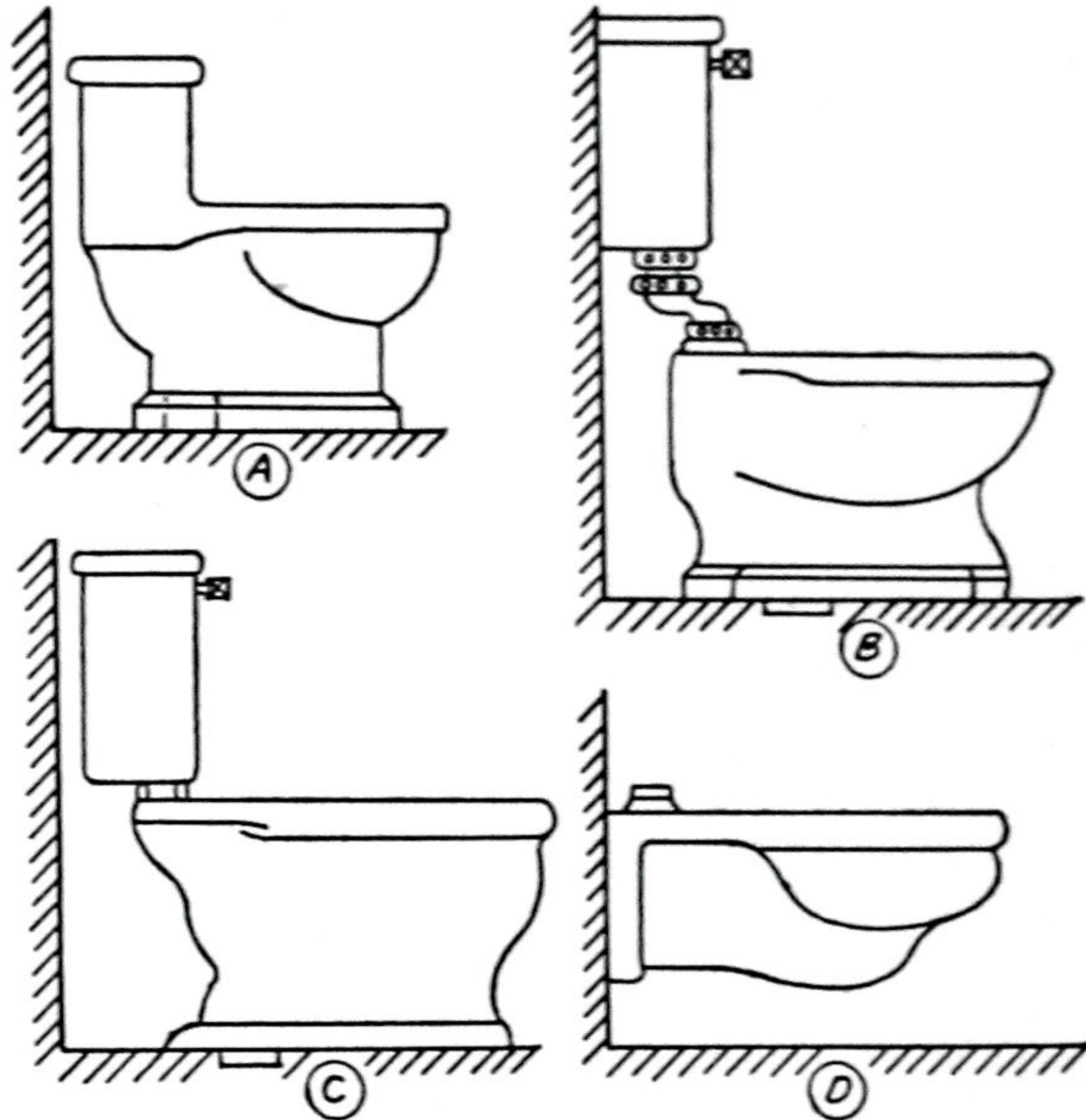


FIG. 9-7. Standard types of closet bowls: (A) integral, (B) low tank, (C) close coupled, and (D) siphon jet.

Combinations are further classified on the basis of distance between the water tank and the closet bowl; an integral combination has the water tank as a part of the bowl itself; a close-coupled combination has a water tank which is separate from the bowl but rests directly on it; while a low-tank combination may have the supply tank mounted as much as 6 in. above the flood-level rim. In high-tank combinations, the water supply tank may be several feet up, in which case a pull chain is provided. Fig. 9-7 shows some of the more popular designs.

A further breakdown depends upon the interior design of the piece, the method by which water is supplied, and the path which the refuse takes in passing from the bowl through the outlet. For example, the unit shown in Fig. 9-7B is known as a "siphon-jet" bowl because the water is supplied from the top of the unit. Thus its complete name is

plete table service. The following is only a partial list, omitting size and weight classifications:

Plates	Bouillon cups	Cream jugs
Individual butters	Bouillon liners	Fruit dishes
Ice cream shells	Coffee cups	Ice tubs
Oval platters	Tea cups	Water jugs
Bakers	Egg cups	Pitcher jugs
Sauce boats	Tea saucers	Match stands
Low foot bowls	Coffee saucers	Coffee mugs
Cereal bowls	Coffee pots	Mustard pots
Sugar bowls	Cake covers	Nappies
Salad bowls	Celery trays	Pickle dishes
Salad comports	Creamers	Casseroles

Hotel china is made in three grades, based on wall thickness: (1) thick china ($\frac{5}{16}$ to $\frac{3}{8}$ in. walls) is used for the more severely handled service, typically at lunch counters and enlisted men's Army messes; (2) hotel (rolled edge) china ($\frac{5}{32}$ to $\frac{1}{4}$ in.) is the normal type for hotel and restaurant service; while (3) medium-weight china (less than $\frac{1}{4}$ in.) is furnished for high class eating places where the service is handled with reasonable care. In recent years, medium-weight hotel china has also found an increasing market for home use; for this purpose it is usually given more elaborate decoration than is normal in restaurant use.

The following are typical batch compositions for three hotel china bodies. Each is fired to Cone 10 to 12.

Material	Body A	Body B	Body C
Ball clay.....	9.5%	7.5%	15.0%
Kaolin.....	33.0	37.0	28.3
Flint.....	35.0	36.0	38.9
Feldspar.....	21.0	18.0	14.8
Dolomite.....	1.5	—	3.0
Whiting.....	—	1.5	—

The body is prepared in a very painstaking manner. The non-plastic materials are first ground together in a ball mill until all will pass a very fine screen (such as 325-mesh). The plastics are carefully blunged into a thin slip and passed through a high-intensity magnetic separator to remove iron particles, then mixed with the non-plastics in the blunger. The resulting slip is again de-ironed, and may either be passed directly to a casting shop or filter pressed for jigged bodies.

The fine particle size of the flint and the high alumina content of the body, combined with high firing, develop a large proportion of mullite crystals in the fired ware. These crystals, bonded together with a high-

porous, a slip coating or engobe of better body material is employed to provide a more suitable surface for the glaze.

On the other hand, many plants manufacture artware with very high grade bodies, some of which approach true porcelain in composition and properties. Several producers specialize on continental-type porcelains, producing wares to fill the market previously supplied by the well-known "Dresden china" ware imported from Germany (Meissen).

It is interesting to note that nearly all the large sanitaryware plants also produce artware. There is a good practical reason for this. The shapes of the sanitaryware pieces are such that it is almost impossible to get a good uniform setting for tunnel kilns using only such large pieces. The inclusion of vases, lamp bases and similar art pieces allows a more uniformly dense ware placing on the kiln cars, thereby improving heat distribution, and reduces firing defects in the sanitaryware.

Because of the very nature of the business, there has been no attempt in the artware field to bring about any type of standardization. Individuality, in fact, is the most compelling sales argument; each producer is constantly striving to bring out something different as regards shape, use, glaze color, glaze texture or decorative treatment. This causes endless variety of wares, and new types are constantly appearing in the retail stores. Many producers attempt to specialize in one line—florist's goods, lamp bases, garden pottery, etc.—for the "bread and butter line," using other miscellaneous items for the "profit line."

These wares are marketed through many channels, including department stores, gift shops, roadside stands, direct mail through advertising in home furnishings magazines, jobbers, theater premiums, and other outlets.

Undoubtedly the number one class of goods in this field is that group of items used in the home in connection with cut flowers and small plants—vases, flower bowls and decorated flower pots. The total output of such goods is fairly steady, varying only with the general prosperity of the times and the quantity of competing imports. Some of the other items are strongly cyclical, following style trends and being influenced by the availability of other materials. Domestic production of ceramic costume jewelry, for example, became of considerable importance during World War II because of the lack of copper, silver, stainless steel, and other metals formerly used.

CONTAINERS

Containers, of both the wide-mouth and narrow-neck types, have been made from whiteware bodies for a number of years. Wide-mouth jars can be fashioned by the plastic jiggering method, but slip casting must be

¹⁰Wainer and his associates have investigated a number of zircon porcelains. The following seemed to have the best electrical characteristics:

Component	Body				
	A	B	C	D	E
Zirconium silicate.....	59.25%	66.7%	68.5%	59.2%	35%
Calcium-zirconium silicate.....	7.41	22.2	22.6	29.6	20
Magnesium-zirconium silicate.....	7.41	—	—	—	10
Barium-zirconium silicate.....	7.41	—	—	—	10
Ball clay (Ky. No. 5).....	18.52	11.1	8.9	11.2	28
Dielectric constant.....	8.2	9.4	9.4	8.6	8
Power factor at 1 m.c.0003	.0005	.0003	.00003	?

All five of these bodies may be satisfactorily matured in the range of Cone 10 to 12 and show total firing shrinkages of about 15%.

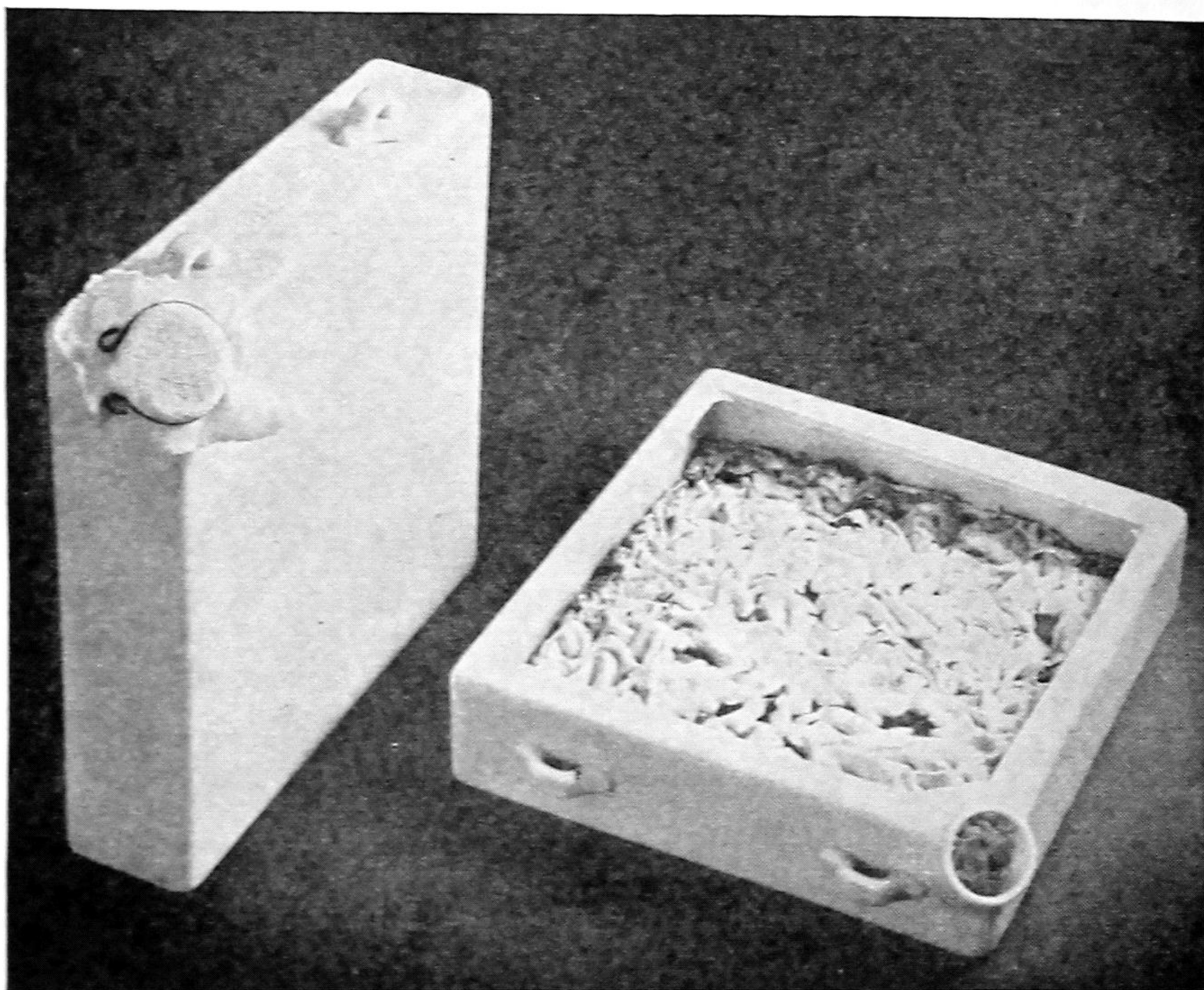
Similar zircon porcelains have been studied by ¹¹Russell and Berberich whose report furnished most of the data shown in Table 11-10. As the data show, many of the properties of low-loss zircon porcelains are intermediate between those of porcelain and clinoenstatite bodies. The zircon

TABLE 11-10. Properties of Zircon Porcelains

Specific gravity.....	3.6-3.8
Water absorption.....	0
Top service temperature, °F.....	1,830-2,000
Coefficient of thermal expansion (per °C., 20-700°C.).....	$(3.68 \text{ to } 4.9) \times 10^{-6}$
Tensile strength, p.s.i.....	12,700
Compressive strength, p.s.i.....	90,000
Modulus of rupture, p.s.i.....	23,000-30,000
Impact resistance, p.s.i.....	253
Dielectric strength (60 cycles, $\frac{1}{8}$ -in. discs) volts/mil.....	280-300
Volume resistivity (500 volts, 60 cycles). ohms/cm. ³	
at 100°C.....	10^{14}
at 600°C.....	$(1 \text{ to } 2) \times 10^9$
Dielectric constant	
at 25°C.....	9.0-10.5
Power factor	
at 1,000 k.c.....	.0005 to .0010
at 10 m.c.....	.0005

porcelains have somewhat higher dielectric constants than either of these two bodies, and this value tends to be augmented with increasing temperature and lower frequencies (the constant of pure zirconia is 18). The zircon porcelains are very dense and impervious, even to high-pressure dye solutions. They are characterized by high strength and

insulates the two wires from each other, preventing short circuiting. Such tubing is made in several sizes, round or oval, with single, double or multiple bore. The second is the pyrometer protection tube, which is often glazed, is gas tight, and keeps the furnace gases away from the metal of the thermocouple leads, thereby lengthening the useful life of the lead wires. Fired at the high temperature of 3,100°F., both types of tubes can withstand continuous exposure to 2,900°F. and are also highly resistant to thermal shock.



Ceramic Industry

FIG. 12-9. Thousands of these culture dishes are now in use, raising the mold for penicillin germicides.

Burner Tips

Small burner tips made of lava or steatite bodies have long been used in a great many types of industrial heating equipment, including core ovens, soft metal melters, brazing torches, mold dryers, electrottype furnaces, bake ovens, pilot lights for domestic water heaters, mine lamps, and heat-treating furnaces. Compared with metal tips or drilled pipe, the ceramic parts have been found to give a far longer service life, as they retain their shape at all temperatures up to 2,000°F. and do not oxidize, soot, burn out or clog with rust.

